Study of the Applications of a Radiant Cooling Panel in Museum Showcases

Likui Yu, Associate Professor
Huabo Hou, Master
Institute of Energy and Power, Huazhong University of Science and Technology
Wuhan P. R. China, 430074
yulikui@sina.com huabohou@163.com

Xiongfeng Wan, Master
Huanxin Chen, Professor
School of Energy Science and Engineering, Central South University
Changsha P. R. China, 410083
xiongfengwan@gmail.com hxchen@mail.csu.edu.cn

Abstract: The radiant cooling panel was proposed to control the temperature in the showcases to supply a steadier environment for cultural relic preservation. The new showcase and the convectional one's temperature and flow field were compared by numerical simulation. More attention was focused on the two different conditions: with and without air-conditioning. It is found that the new showcase's isothermals distribute more regularly than the convectional one, and its zone for the cultural relic's preservation is also larger than the convectional one. It is also found that the velocity magnitude of the new showcase is much smaller than the convectional one, which is good for the cultural relics.

Key words: radiant cooling panel; temperature control; cultural relic conservation; showcases; numerical simulation

1. INTRODUCTION

During the last decade, a large number of studies have been conducted in the design, modeling, and testing of environment control system of showcases in museum [1~3]. This paper reviewed the recent researches and developments systematically, and found that the interior temperature in conventional showcase is controlled by means of centralized air-conditioning system, which supplied conditioned air with air duct [4~6]. However, this conventional system can't maintain the temperature at a required level. The temperature varies continually owing to unstable operation, even stop sometimes for problems of the centralized air-conditioning system [7]. Frequent fluctuation of temperature may accelerate the cultural relics' deterioration; therefore, it is unaccepted for permanent preservation [8].

It is strongly desired to find a method to keep the temperature at a stable level so that the cultural relics can be conserved under a good condition. In the circumstances, the radiant cooling panel is proposed to control the temperature in the showcases [9]. And the operating principle and advantages of this new showcase are presented particularly in this paper.

The objective of this paper is to investigate the differences between the new showcase and the conventional one. So the calculating models of these two kinds of showcases are developed respectively on the basis of considering their exterior parameters, interior radiation and thermal characteristics of their material. Attention was then focused on the simulation and analysis of the temperature field and flow field inside these showcases. Two conditions are taken into count: one is the showcases in the exhibit hall that with air-conditioning environment, the other is the showcases in the exhibit hall without air-conditioning environment.

2. NEW SHOWCASE

2.1 Operating Principle

Fig.1a shows the geometry of the new showcase installed radiant cooling panel. Pipes through which chilled water flows are disposed in parallel in the left panel of the showcase. The pipes lie close to the panel surfaces, and they cool the showcase via natural convection and radiation heat transfer [9].

2.2 Compared with the Conventional Showcase

One kinds of the conventional showcases' configuration is schematically shown in Fig.1b. From the picture it can be seen that there are two openings

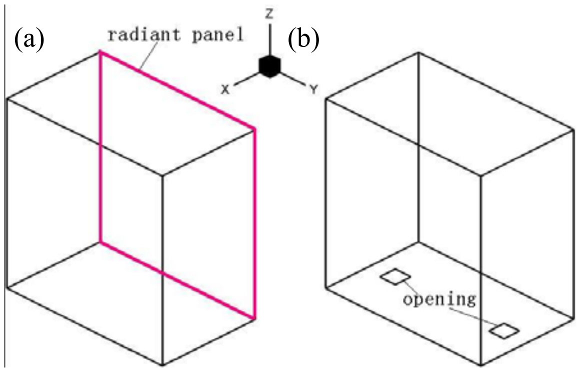

Fig. 1 Configurations of two showcases

(a) new showcase ; (b) convectional showcase

locate respectively at left and right sides of the bottom panel, different from the new showcase. The preconditioned air is vented through one opening, and exhausted by the other to control the showcase' inside temperature. However, the temperature varies continually owing to unstable operation, even stop sometimes for problems of the centralized air-conditioning system. It goes against cultural relics' permanent preservation. Relative to the conventional showcase, the new one is excellent in some aspects listed as follow:

- Maintain the temperature stably. When cooperate with phase change material, its temperature can be kept at a stable level well in the case of HVAC's unstable operation, even stop.
- Save energy. It has been validated that the radiant cooling panel can make a 28% to 40% reduction in energy usage compared the conventional HVAC system [10].
- Reduce the damage to the cultural relics cause by air flow. Michalski suggested that the HVAC supply air should not be blown into exhibition cases, because it could make impact on what are usually the most sensitive objects [8]. Without blowing air into cases directly, the new showcase can offer a better environment for cultural relics.

3. NUMERICAL ANALYSIS

3.1 Physical Model

The physical models and the coordinate systems of the two kinds of showcases have been schematically shown in Fig. 1. Like the familiar showcase, most surfaces of the new showcase are glass panel except bottom and the side that close to wall so that the cultural relics can be seen from several directions by visitor.

The dimensions of the two showcases are 0.6m×1m×1m, and the convectional one's two openings sizes are 0.1m×0.1m respectively.

3.2 Numerical Method

In order to simplify the problems, some presuppositions are listed as follows:

- The flow is steady and incompressible;
- All panels are black;
- The air contained in the box is assumed to be absorbing and emitting;

Since the temperature difference inside is a main force for the buoyancy flows, the Boussinesq approximation, which relates density change with temperature difference, was employed. Standard k–ε model was adopted as the turbulent model and the standard wall functions are needed. The radiation transfer in the new showcase was modeled using DO model.

The simulations use the finite volume differencing scheme and SIMPLE algorithm [11]. The third-order QUICK differencing scheme [12] was used to evaluate the convection terms, the energy equation and the turbulent transport equation. Structured Cartesian meshes are used to discretize the cases. Finer grids were used for more critical areas such as openings and the region near to the panel. The numerical calculation was performed using the Computational Fluid Dynamics package Fluent, version 6.1.

3.3 Boundary Conditions

In order to study the differences between the new showcase and the convectional one roundly, two conditions are considered. One is the showcases in the exhibit hall that with air-conditioning environment, the other is the showcases in the exhibit hall without air-conditioning environment. However, limited to the physical model, the temperature of the glass panel was fixed as the value of the environment temperature. And the bottom panels of two showcases were considered to be adiabatic. The convectional showcase's inlet temperature and speed were fixed as 7℃ and 1m/s respectively. The boundary conditions for the considered problems are determined in Table1.

Tab. 1 boundary conditions

	Glass panel temperature (℃)	Radiant cooling panel temperature (℃)
New showcases		
AC	22	7
without AC	37	7
Convectional showcases		
AC	22	adiabatic
without AC	37	adiabatic

4. RESULTS AND DISCUSSION

4.1 Temperature Distribution

Temperature in exhibition and storing areas of collections of cultural character is one of the important factors of deterioration. Inhomogeneous temperature distribution inside showcase may lead to accelerate the deterioration of the cultural relics. Wilson suggested that a constant temperature with the rage from deep-freeze to about 18□ (291K) would be suitable for storage of paper records[13]. The value of 18□ (291K) then was taken as a criterion to judge the two showcase consequently.

4.1.1 Case 1 (air-conditioning environment)

Fig.2 shows the isothermals of different cross sections of these two showcases on the condition of air-conditioning environment. The upside of the Fig.2 are isothermals of new showcase, it can be seen that the isothermals in the *x*-*z* cross section start from top left corner to the bottom, like emanative ray. Because of the radiant cooling panel, the isothermals near the left distribute thick and fast. It also can be found that the isothermals distribute by parallel approximately along direction that plumb the left panel. This distribution characteristic means that temperature in the slightness zones that between the isothermals doesn't vary; therefore these zones are fit for preservation of flat cultural relics, such as papery material. Taking the isothermal (T=291K) as the division, the left part of the cross section is becoming to preserve cultural relics, whose shape is similar to the triangle prism. As be seen from the upper of Fig.2, the isothermal configurations of the *x*-*z* cross section are almost similar. The *y*-*z* cross section shows that there are three thermal boundary layers developed near the left, right and up panel. And the shape of the isothermal (T=291K) is similar to half of ellipse due to the effect of three high temperature panel. So the configuration of the triangle is become small gradually with approaching to high temperature. Fig.3. shows the configuration of the zone that for preserving cultural relics schematically. From it we can see that the zone for conserving cultural relics in the new showcase likes a triangular prism, which right-angle side is the radiant cooling panels.

Compared with the new showcase, the convectional showcase's temperature distributes irregularly. As been shown in Fig.2, the isothermals below291K concentrate on the area near to the inlet, and the zone is a little small that the isothermal (T=291K) is near to the bottom in the *x*-*z* cross section of y=0.5m. Temperature in this zone is changed acutely too. So the cultural relics can't be placed here. From the *y*-*z* cross section of x=0.3m, it can be found that the temperature in the right down part which away from inlet flow is only determined by the natural convection, so it is changed gently. This zone is fit for the preserving, but it is very small. In the Fig.3, it is a cuboids structure exscinded the left part which is the zone of inlet flow.

4.1.2 Case 2 (without air-conditioning environment)

Fig.4 shows the isothermals of different cross sections of these two showcases in the environment that without air-conditioning. Under this condition, the glass panel of the showcase's temperature was considered as 310K (37℃).Because of the high temperature, both of the showcases' inside average temperature is higher than that in case 1. From Fig.4 we can see that the isothermals (T=291K) of the new showcase is very close to the radiant panel, the zone that can be used to preserving the cultural relics is

ESL-IC-06-11-217

very narrow too. However, the distribution of isothermals is regular like in case 1. So it can be used for preserving some materials that don't restrict with

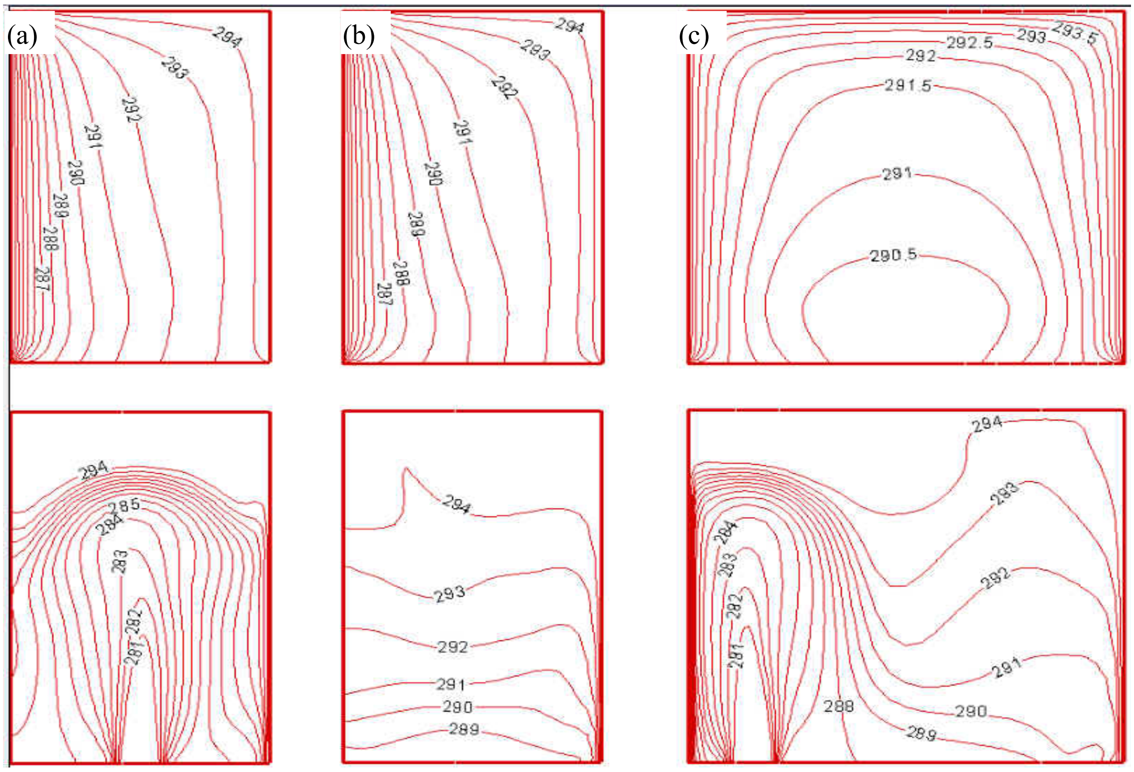

Fig. 2 the new showcase (up) and convectional showcase' (down) isothermals of different cross sections on the condition of the air-conditioning environment

(a) *x*-*z* cross section (*y*=0.15m); (b) *x*-*z* cross section (*y*=0.5m); (c) *y*-*z* cross section (*x*=0.3m)

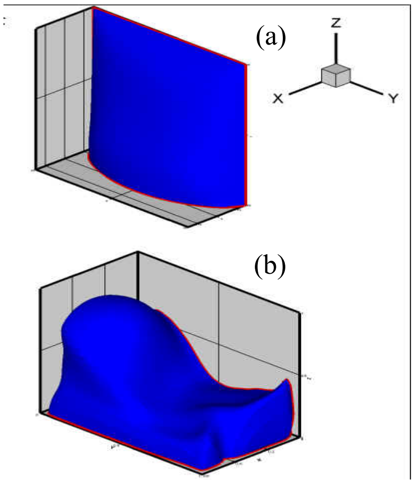

Fig. 3 Iso-surfaces of temperature (*T*=291K)

(a) new showcase;(b) convectional showcase

temperature. And the distribution of the isothermal of convectional showcase, as be seen from Fig.4, is irregularly too. In all, these two showcases' temperature distribution is unreasonable due to the increasing of exterior temperature.

4.2 Velocity Distribution

To protect the cultural relics well, the low velocity is needed customarily, so the lower of the

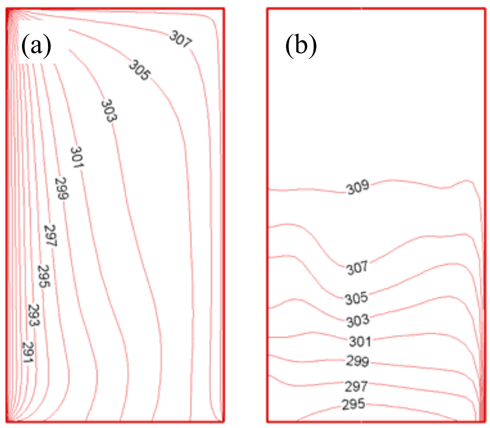

Fig. 4 Isothermals of *x*-*z* cross section (*y*=0.5m) without air-conditioning

(a) new showcase; (b) convectional showcase

velocity in the showcase, the better the environment is in it for the cultural relics.

4.2.1 Case 3 (air-conditioning environment)

The two showcases' velocity nephograms of different cross sections are schematically show in Fig.5. Without forcing vent, the new showcase' flow field is dominated by buoyancy flows. And the main force for the buoyancy flows is temperature

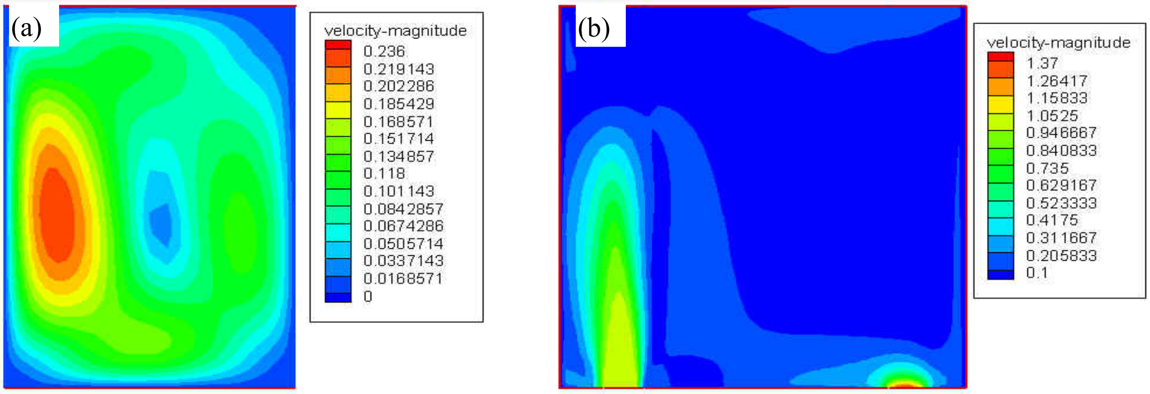

Fig. 5 Velocity nephograms of different cross sections

(a) new showcase's *x*-*z* cross section (*y*=0.5m); (b) convectional showcase's *y*-*z* cross section (*x*=0.3m)

difference. Hence its velocity magnitude is determined by the temperature difference. From the Fig. 5, it can be seen that the maximal velocity of the new showcase is 0.236m/s, and the convectional showcase is 1.37m/s which is six times bigger than that of the new one. And with the effect of buoyancy, the air flows downwards along the radiant cooling panel, the flow structural is a regular vortex. This flow structural is fit for preserving cultural relics, especially papery materials. However, the convectional showcase's flow structural is anomalistic.

4.2.2 Case 4 (without air-conditioning environment)

As been shown in Fig.6, the maximal velocity of the new showcase increases from 0.236m/s to 0.422m/s. The reason is the temperature difference, which is the main factor of velocity magnitude, has been increased with the external temperature varies from 295K to 310K, obviously the increasing of the velocity is not good for the cultural relics. Relative to the new showcase, the convectional one's maximal velocity decreases a little instead of increasing because the increased buoyancy reduces the flow velocity. However, the magnitude of the convectional showcase velocity is still bigger than the new one. Therefore, the new one is fit for preserving of the cultural relic.

5 CONCLUSIONS

In the present work, two showcases' temperature and flow field were compared by numerical simulation, the efforts have been concentrated on the two different condition: air-conditioning and without air-conditioning. Some simple conclusions are drawn as follows:

1) The new showcase's isothermals distribute more regular than the convectional one, and its zone which fits for the cultural relic's preserving is similar to a triangle prism. It is about one-third of the showcase, which is bigger than the convectional one.
2) As the exterior temperature increases, i.e. exterior environment is changed to without air-conditioning. Both of the showcases' zones which fit for the cultural relic's preserving become more and more small. So the exterior temperature plays an important role on showcase's interior temperature field.
3) The velocity magnitude of the new showcase is very smaller than the convectional one, which is good for the cultural relics.

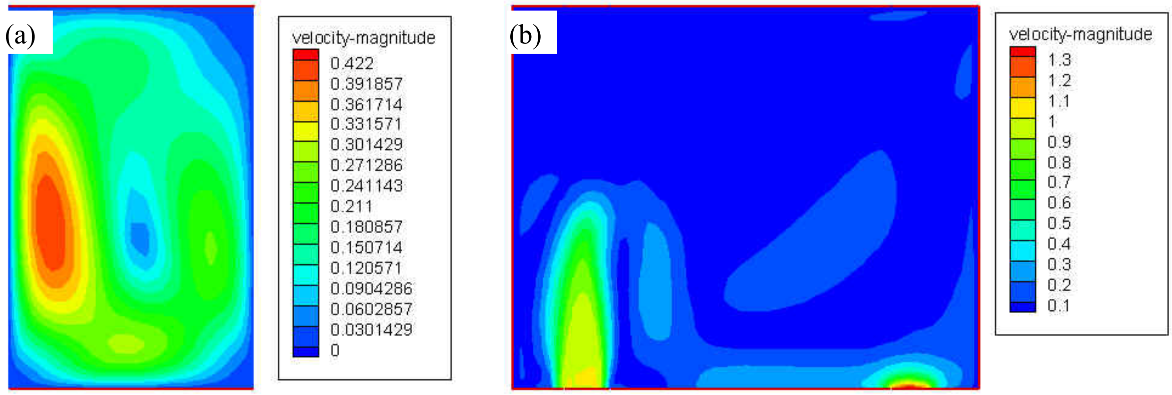

Fig. 6 Velocity nephograms of two showcase's cross sections

(a) new showcase's *x-z* cross section (*y*=0.5m); (b) convectional showcase's *y-z* cross section (*x*=0.3m)

REFERENCES

[1] Svare Soren. Climate-Conditioned Display Case for Lorich's Map of the Elbe in the Hamburg Public Records Office[J]. Museum Management and Curatorship, 1999, 18 (2):193-204.

[2] Tim Padfield. a cooled display case. http://www.padfield.org/tim/cfys/coolcase/coolcase.pdf.

[3] Tim Padfield. A cooled display case for George Washington'scommission.http://www.padfield.org/tim/cfys/coolcase/coolcico.pdf.

[4] Tim Padfield. The Control of Relative Humidity and Air Pollution in Show-Cases and Picture Frames[J]. Studies in Conservation, 1966, (4):8-30.

[5] Yu D，Klein S A，Reind D T. Investigation of solid adsorbents for humidity control in display cases. In：ASHRAE Transactions，2002，108（pt1）:306-315.

[6] Catherine E Miles. Wood Coatings for Display and Storage Cases[J]. Studies in Conservation, 1986, 31(8):114-124.

[7] Catherine Sease. The Development of the Humidity Control Module at Field Museum[J]. Journal of the American Institute for Conservation, 1991, 30, (3): 187-196.

[8] ASHRAE. Chapter 20, "Museums, Libraries, and Archives," in 1999 ASHRAE Applications Handbook (SI edition or I-P edition). Atlanta GA 30329, USA.

[9] John Dieckmann, Kurt W. Radiant Ceiling Cooling[J]. ASHRAE Journal 2004(6):42~43.

[10] H E Feustel，C Stetiu. Hydronic radiation cooling-preliminary assessment[J]. energy and building, 1995, 22:193-205.

[11] Patankar S V. Numerical heat transfer and fluid flow[M]. Washington DC, 1980.

[12] Leonard BP. A stable and accurate convective modeling procedure based on quadratic upstream interpolation. Computer methods in applied mechanics and engineering. 1979;19:59-98.

[13] William K Wilson. Environmental guidelines for the storage of paper record[S]. NISO TR01-95, USA.